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The CNT Supply Chain from the Customer's Perspective

2nd Joint Workshop on Measurement Issues in Single Wall Carbon Nanotubes: Purity & Dispersion

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NIST Gaithersburg, MD, USA

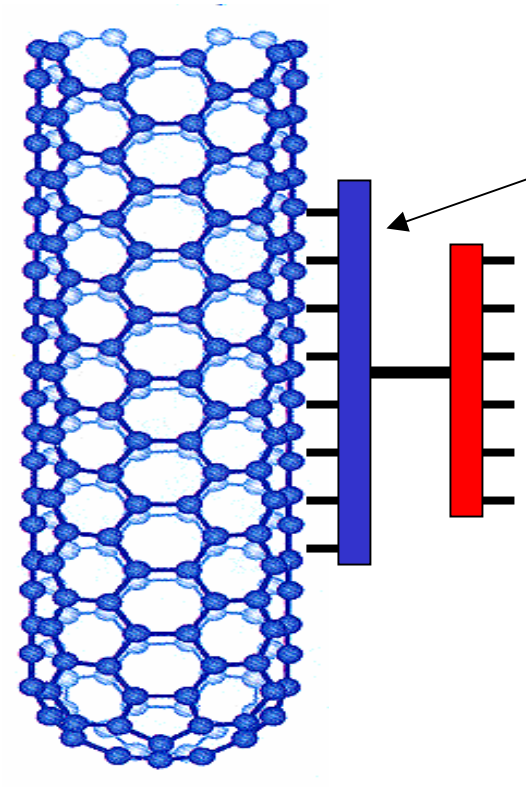
Our Vision

To be the leading worldwide supplier of tools, products, and services that enable adaptable, affordable, and molecularly precise manufacturing.

zyvex®

The Zyvex Approach:
NanoSolve™ Materials

Core Competence: Functionalization



Kentera™ functionalization technology

- **Two distinct functions:**
  - Non-damaging binding
  - Customizable
- **Binding applicable to CNTs (SWNTs, DWNTs, MWNTs)**
- **Functionality may be customized for different applications:**
  - Dispersion in solvents
  - Adhesion to composites
  - Other chemical functionality

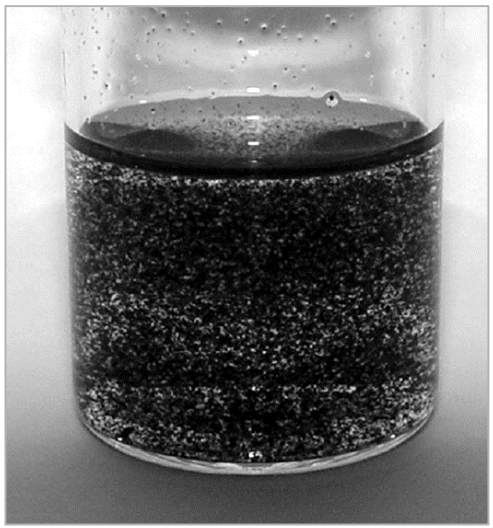
NanoMaterials Vision

- Capitalize on unique properties of carbon nanotube reinforcement for high performance composite materials
  - High strength
  - Low weight
  - High thermal conductivity
  - High electrical conductivity
  - High chemical and thermal stability

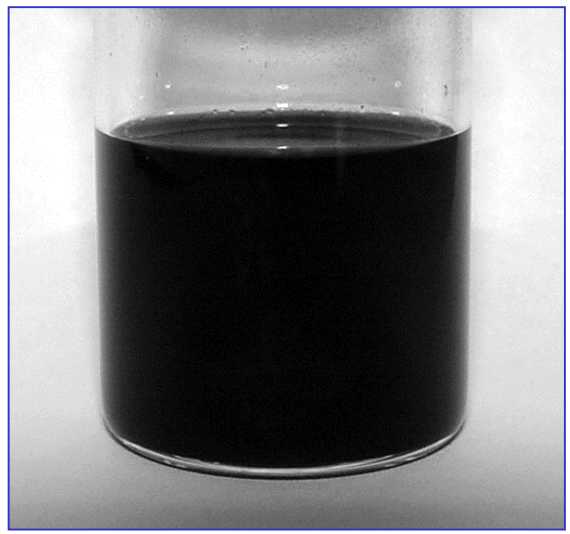
NanoSolve Polycarbonate

NanoSolve™ Dispersion

Product Comparison

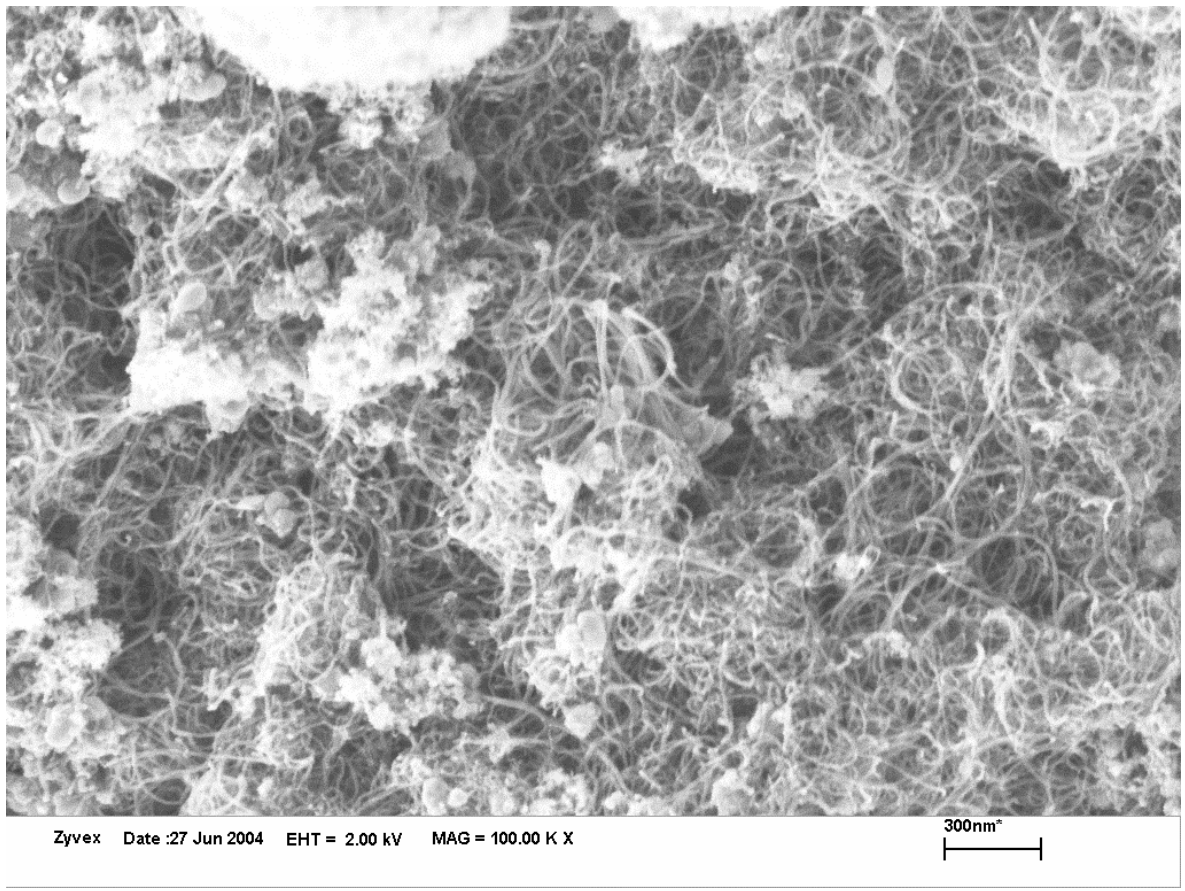


Raw CNT product



Zyvex NanoSolve additive

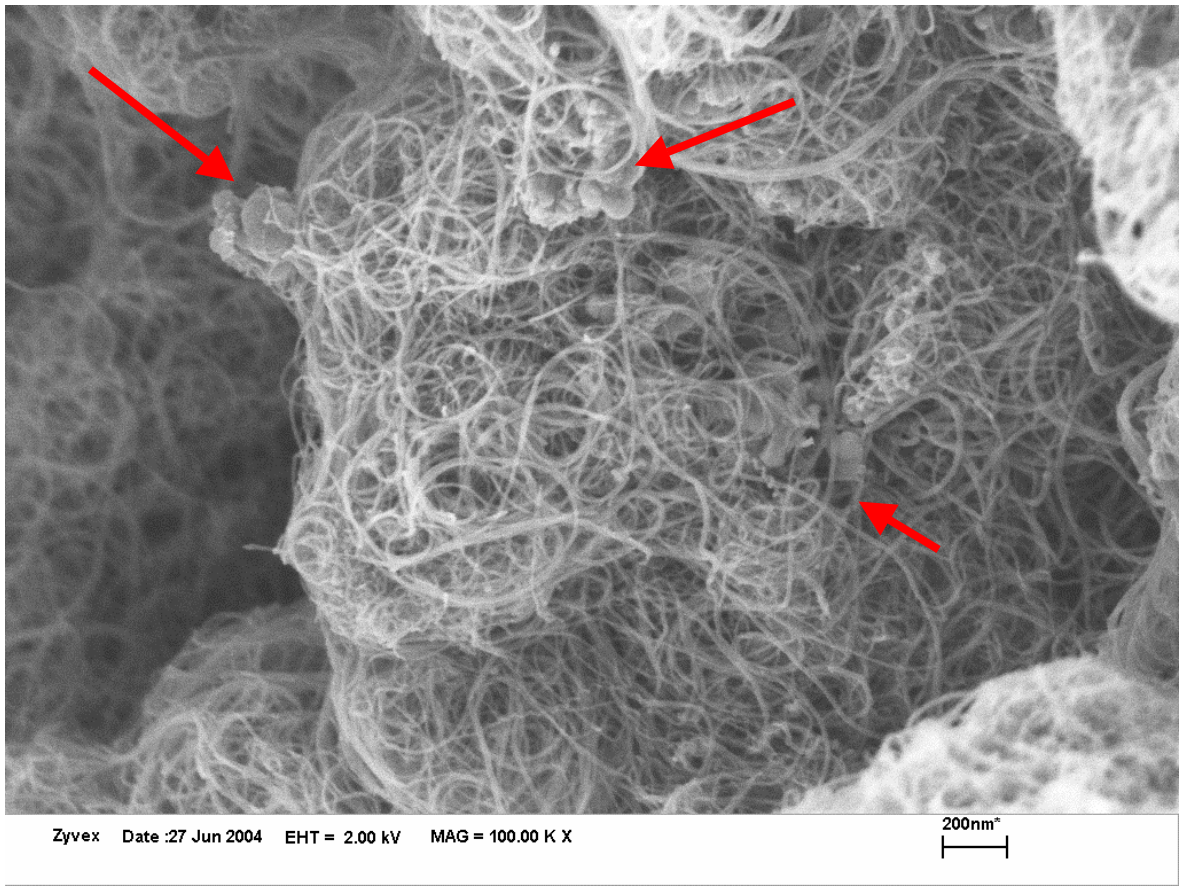
Impurities in Raw CNT



Phase Separation

- Soft floc or sediment
- Could not be redispersed
- Elemental analysis confirms amorphous carbon or soot
- Several microns or greater in diameter
- Required additional filtering steps ($)
- At $500/g, this means $100/g spent on waste
- Does not compete for dispersing agent

Impurities in Filtered CNT



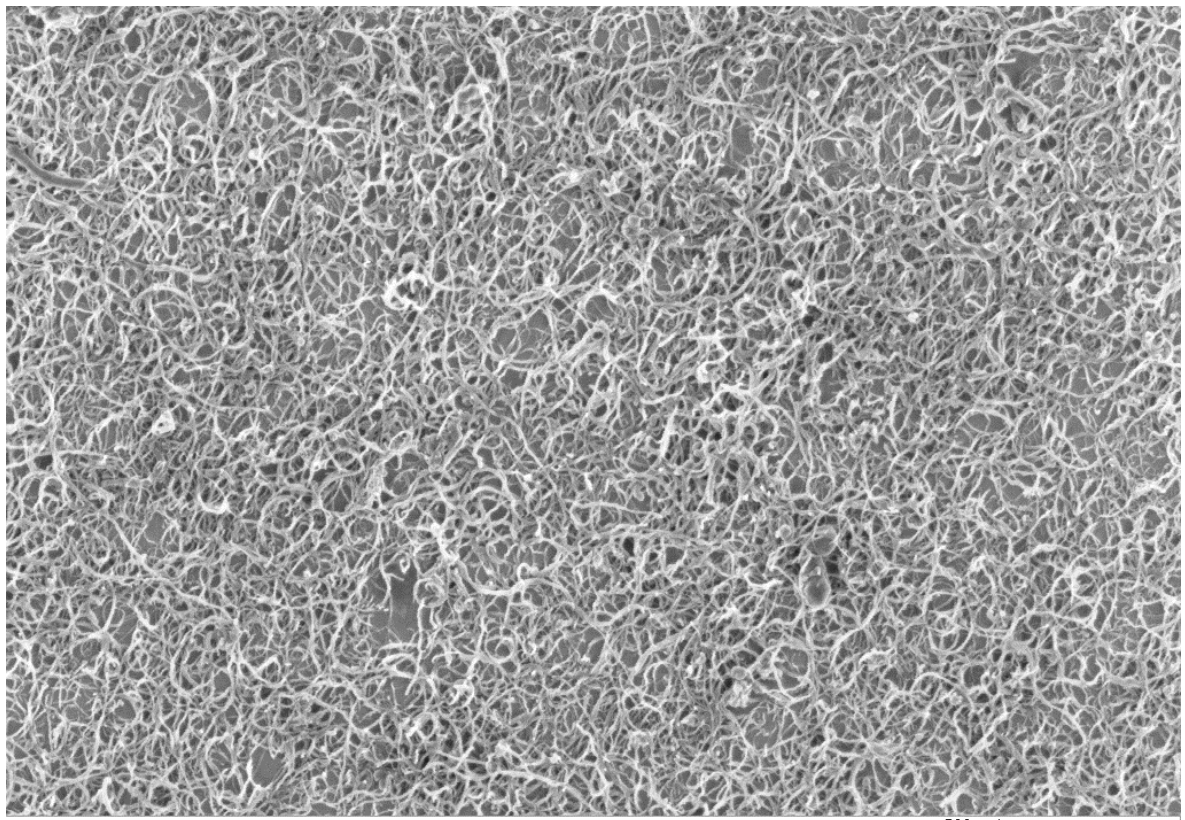
Foreign Matter in Dispersion

- X-ray analysis confirms metal particles (Fe)
- SEM shows them to be 200-300 nm in diameter
- CNTs adhering to trace catalyst material
- Cannot be filtered
- Cannot be exfoliated
- At $500/g, this means $50/g spent on waste

Tolerances

- **CNT content**
  - Must be at least 90%, preferably >95%
- **Amorphous carbon or soot**
  - Must be <10%, preferably <5%
  - Minimal filtering acceptable
- **Iron**
  - Must be <3%, preferably <1%
  - Each iron particle removes dozens of CNTs

Acceptable Raw CNTs



Supply Chain QA/QC

- **ASTM D1514**
  - Gravimetric (measures retained material)
  - Force material through 325 mesh with water spray
  - Measures soot in carbon black
  - Fast and cheap
  - Operationally acceptable

- **ASTM E394**
  - Measures iron spectrophotometrically
  - Fast, cheap, and accurate

Customers' Expectations

- **Property enhancement with CNTs**
  - Thermal
  - Electrical
  - Mechanical

- **Use of CNTs**
  - Little or no reformulation
  - Little or no process changes
  - Little or no capital costs
  - Product stable
    - Is made reproducibly
    - Qualities of interest measurable with established tolerances

What Makes a Nanotube Product?

- **Physical/Structural Properties of CNT**
  - Length
  - Diameter
  - Aspect ratio
  - Surface area
  - Fractal dimension
  - Defects
  - Chiral number
  - S/D/MWNT
- **Impurities**
  - Amorphous carbon
  - Trace metals
  - Trace inorganics

What Makes a Nanotube Product?

What is our customer’s perspective?

Customer's Formulation Approach

- A real industrial process is variable
  - Probabilities replace determinism
  - Tolerances replace absolute values
- Exact cause-and-effect not possible
  - Too many processing variables
  - Too many component parts
  - Possible unknown interactions
- A consistent material described by a possibly incomplete set of factors is more valuable and practical than a variable material about which every factor is known

Consistency: A Customer's View

- There must be basic information about a CNT product
  - Composition
  - Purity
- The product must be supplied the same way each time
- The supplier must be able to scale production to meet demand without affecting quality
- The supplier has to be able to record, document, and explain how it does all of this to a customer

Customers' Interests in QA

- Clear, understandable measurement methods
- Metrics tied to the performance of our own products
- Applications to our own supply chain
  - Grade changes
  - Scalability
  - Product comparison
- Metrics are factors in their own formulation design

Purity, Quality, and CNTs

- A customer only needs enough information
- That information needs to be directly tied to a processing variable or concern
- Purity and quality standards for manufacturing can and will be less complete scientifically than for research applications
- Tests for purity and quality can be simple and straightforward
- No need for overquality

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